Recommendations for Downlink Data Subchannel and Pilot Format Design in IEEE 802.16m

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Fred Vook, Tim Thomas, Mark Cudak, Bishwarup Mondal, Fan Wang, Kevin Baum, Jeff Zhuang, Amitava Ghosh

Motorola

E-mail: fred.vook@motorola.com

*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Venue:

TGm Call for contributions on 802.16m System Description Document, IEEE 802.16m-08/005.

Topic: "Pilot Structures as relevant to downlink MIMO" and "Downlink Physical Resource Allocation Unit"

Abstract:

Recommendations for Downlink Data Subchannel and Pilot Format Design in IEEE 802.16m

Purpose:

Adoption of recommendations into the 802.16m System Description Document

Downlink Data Subchannel and Pilot Formats: **Overview**

- Design considerations and recommendations for:
  - Basic “Resource Tile” for Downlink Subcarrier to Subchannel mapping
  - Pilot & Data layout for the basic resource tile
  - Dedicated Pilots versus Broadcast Pilots
- Recommendations based on:
  - Need to efficiently support the best-performing CL MIMO strategies.
  - Comparisons & evaluations based on throughput simulations accounting for both FER performance and pilot overhead

Considerations for DL Data Subchannel Design (1)

- Need to efficiently support high-performance Closed-Loop MIMO transmission methods:
  - Beamforming
  - Single-User MIMO (SU-MIMO)
  - Multi-User MIMO (MU-MIMO)
- Support up to rank 4 transmission
  - 2-stream SU-MIMO for handsets
  - 4-stream SU-MIMO for CPEs / Laptops
  - 4-user MU-MIMO for all MS classes
- Enablers for Closed-Loop MIMO transmission:
  - TDD reciprocity (UL Sounding / UL transmission) (requires dedicated pilots)
  - Codebook feedback (can use broadcast or dedicated pilots)
  - Direct/analog feedback (requires dedicated pilots)

Need to balance pilot overhead with system performance

Considerations for DL Data Subchannel Design (2)

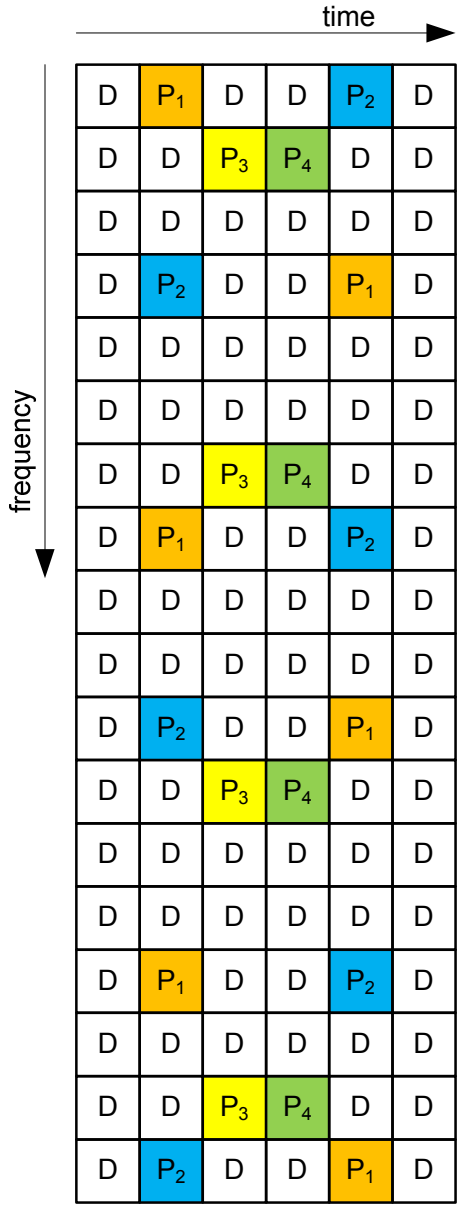
- Need dedicated pilots:
  - DL MU-MIMO enabled with TDD reciprocity or with Direct / Analog Feedback clearly outperforms DL MU-MIMO enabled with Codebook Feedback
    - Dedicated Pilots are required when using TDD Reciprocity or Direct / Analog Feedback to enable DL-MU-MIMO
- Need narrowband subchannels for low speed
  - Support frequency selective closed-loop transmission & scheduling
- Need diversity subchannels for high speed
  - Exploit frequency diversity
- Need self-contained resource tiles
  - Better support for the use of dedicated pilots
  - Better support for frequency selective transmission and scheduling
  - Can be grouped to support both diversity and narrowband subchannel definitions

Recommendations for DL Subcarrier to Subchannel Mapping

- Basic Resource Tile (RT) for data subchannels
  - 18 subcarriers x 6 symbols sub-block format
- Several versions of the Basic RT are considered to accommodate the following:
  - Dedicated and broadcast pilots (See C802.16m-08/122)
  - Different numbers of effective transmit antennas & spatial streams
- Rate matching is assumed within the tile for flexibility in supporting different numbers of transmit streams / antennas
  - See Contribution C802.16m-08/010
- A subchannel consists of some number (TBD) of these Basic RTs
  - FEC is performed across the RTs that make up a subchannel
  - Narrowband subchannel: RTs in a subchannel are adjacent in frequency
  - Diversity subchannel: RTs in a subchannel are scattered across the band

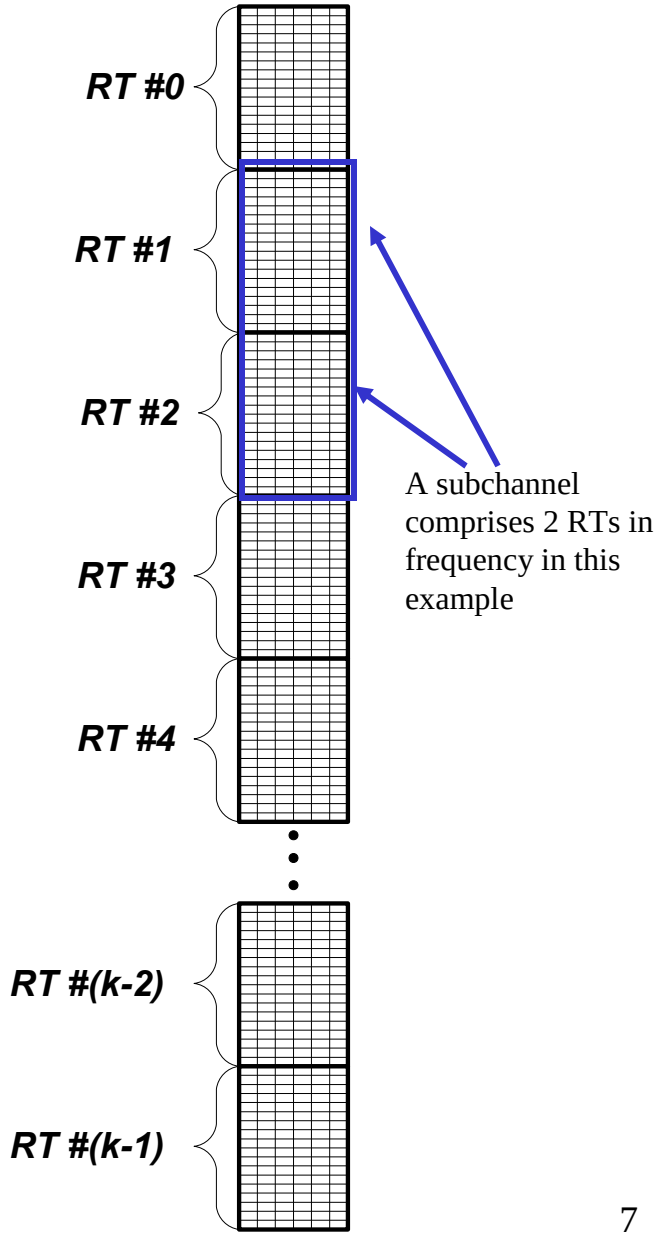
Proposed Resource Tile with Dedicated Pilots

- Supports arbitrary number of Tx antennas with up to 4 spatial streams
- Notation:
  - D=data symbol location
    - Spatial streams represent the third dimension in the diagram to the right
  - Pn=pilot transmitted by stream n.
    - Other spatial streams are null in those positions
    - When number of streams is n, then positions p_{n+1} to p_4 are replaced with data.
      - FEC rate matching is assumed
- Overhead:
  - Pilot overhead depends on the transmission rank:
    - 5.56% overhead for one data stream
    - 11.11% overhead for two data streams
    - 18.52% overhead for four data streams
  - Very small overhead for transmitting a single data stream (when using 4 or more Tx antennas) compared to broadcast pilots
- Channel Estimation:
  - Some simple channel estimators possible (e.g., MMSE, linear interpolation)
  - Rays up to 13.1 usec can be estimated using only a single OFDM symbol for streams 1 and 2 (higher when considering all pilots)
  - Pilots available at RT edges (for streams 1 and 2) to improve channel estimation performance
  - Streams 3 and 4 best used for lower speeds
    - If streams 3 and 4 have lowest modulation and coding rates, then higher speeds may be supported
    - RT designed assuming the transmission mode is most often 2 streams or less
  - Time interpolation/tracking possible for streams 1 and 2 (e.g., MMSE, linear interpolation)



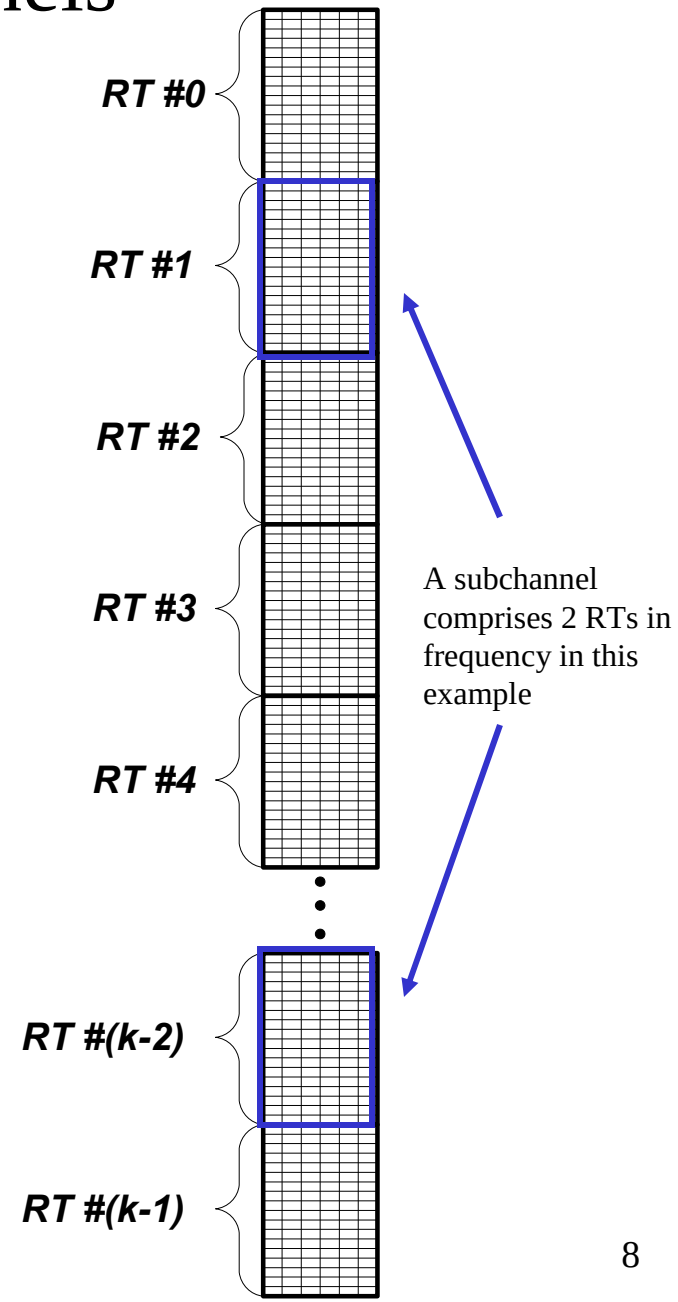
Narrowband Subchannels

- For frequency-selective scheduling and multi-user diversity
- Important for low velocity situations
- Resource tiles comprising a subchannel are adjacent / contiguous in frequency



Diversity Subchannels

- For frequency-non-selective scheduling
  - Important for high velocity situations
- Resource tiles comprising a subchannel are scattered throughout the frequency band (coded together)
- Clear matching of data with the dedicated pilots
  - Avoids the major group restriction in PUSC where all subchannels assigned to a major group had to be beamformed together, which constrained the scheduling of small packets



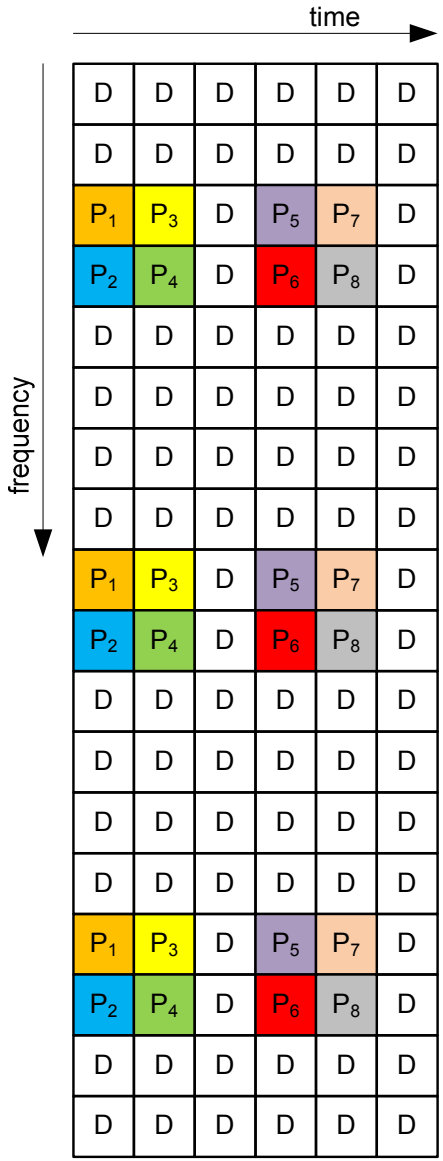
Performance Comparisons

- Downlink with 4 or 8 Tx antennas (l/2 spacing, vertical polarization) and 2 or 4 Rx antennas (independent fading)
- 3 degree angular spread at the base, 3 kph, modified PedB channel
- Single RT data allocation
- Codebook Feedback (TDD or FDD):
  - Tx weights:
    - One weight per RT
    - Equal gain for SU-MIMO (modulation and coding rate can be different on each stream), number of streams adapted to current channel
    - Weights calculated using subspace averaging (see Asilomar 2007 paper*)
  - 4 bit codebook for 4 Tx and 6 bit codebook for 8 Tx *
    - Midamble used for codebook selection for dedicated pilots
    - Broadcast pilots used for codebook selection for broadcast pilots
  - Codebook indices chosen using DL channel estimates and fed back error free
- Eigenvector Feedback (FDD)
  - Dominant Eigenvector fed back
- UL Sounding (TDD):
  - UL sounding from all MS antennas simulated with channel estimation
    - Sounding matched to RT, 18dB DL-UL total power difference, power concentration on UL Sounding
  - Tx weights:
    - One weight fixed over a RT
    - Equal gain singular vectors for SU-MIMO (modulation and coding rate can be different on each stream), number of streams adapted to current channel
    - Regularized ZF for MU-MIMO
- Ideal user grouping for MU-MIMO: MSs separated by at least 15^{o} in angle and have selected different codebook entries.
- MMSE channel estimation on DL
  - Dedicated pilots: confined to RT
  - Broadcast pilots: over all RTs in frequency with interpolation across RTs in time
- Rx weights for SU-MIMO: successive cancellation
- Rx weights for MU-MIMO: linear MMSE interference suppression

*B. Mondal, et. al., “Rank-Independent Codebook Design from a Quaternary Alphabet,” Asilomar 2007.

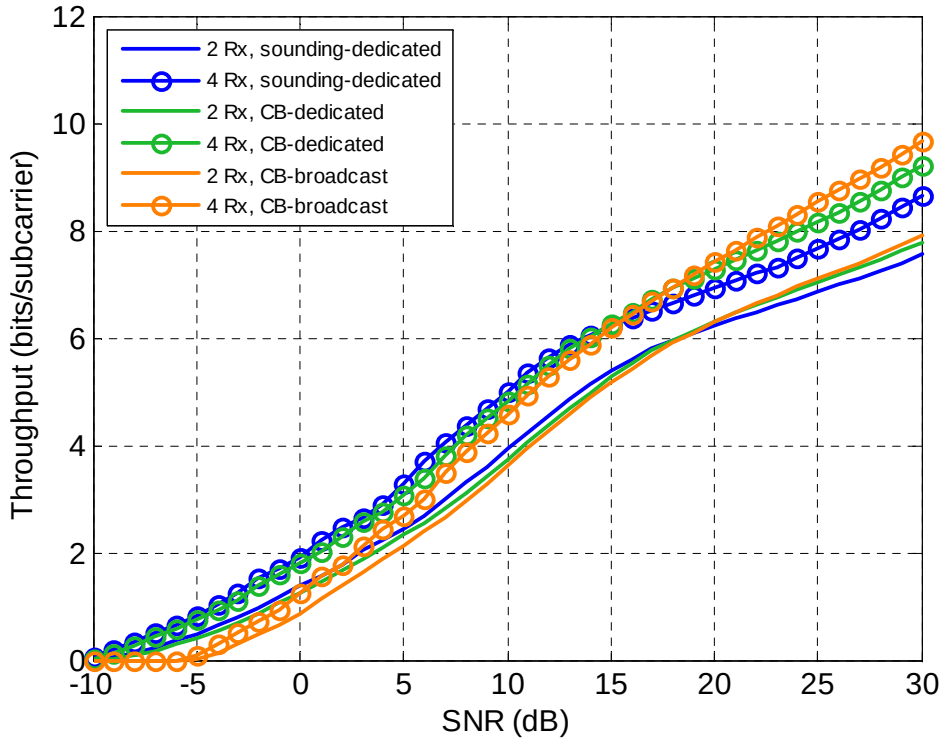
Broadcast Pilot Format Used in Simulations

- Notation:
  - D=data symbol location
  - Pn=pilot transmitted by antenna n
    - Other antennas are null in those positions
    - When number of antennas is n, then positions p_{n+1} to p_8 are replaced with data (FEC rate matching is assumed)
- Format only for comparison purposes to dedicated pilots
- Rays up to 15.2 usec can be estimated using only a single OFDM symbol
- Good time interpolation possible using adjacent resource tiles (RTs)
  - Right at the Nyquist rate (in time) for 350 kph at 2.5 GHz (hence gains available at lower speeds)
- <u>Pilot overhead depends on number of TX antennas:</u>
    - 11.11% overhead for 4 Tx antennas
    - 22.22% overhead for 8 Tx antennas
- Channel estimation in simulations:
  - Three RTs in time plus all RTs in frequency used for channel estimation
  - MMSE channel estimation in frequency followed by MMSE channel estimation in time

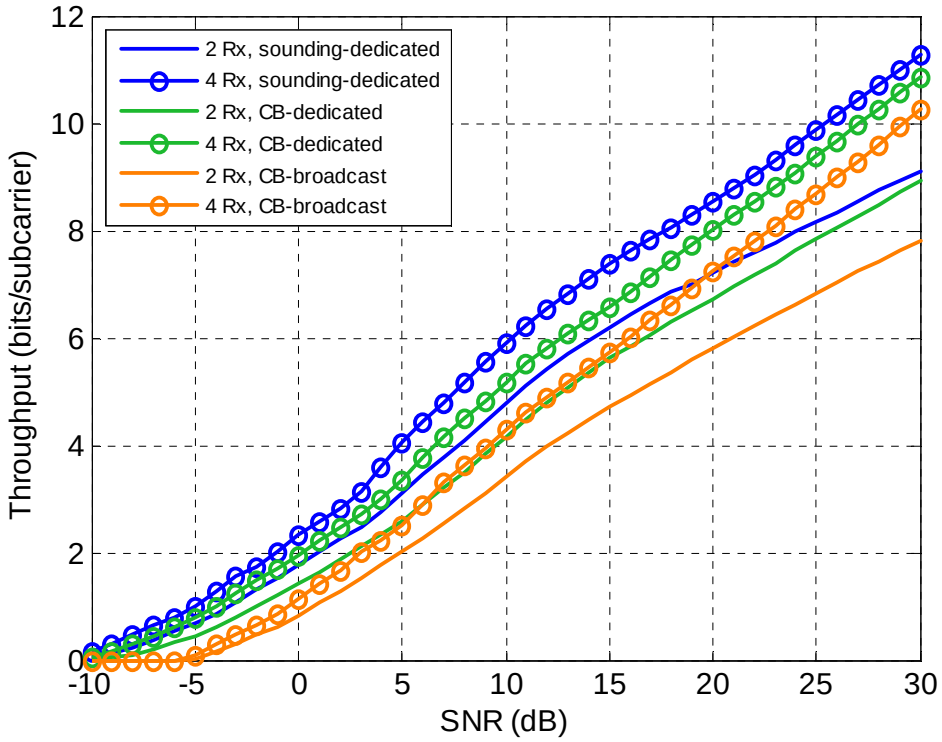


Performance Comparisons for SU-MIMO

4 Tx antennas



8 Tx antennas

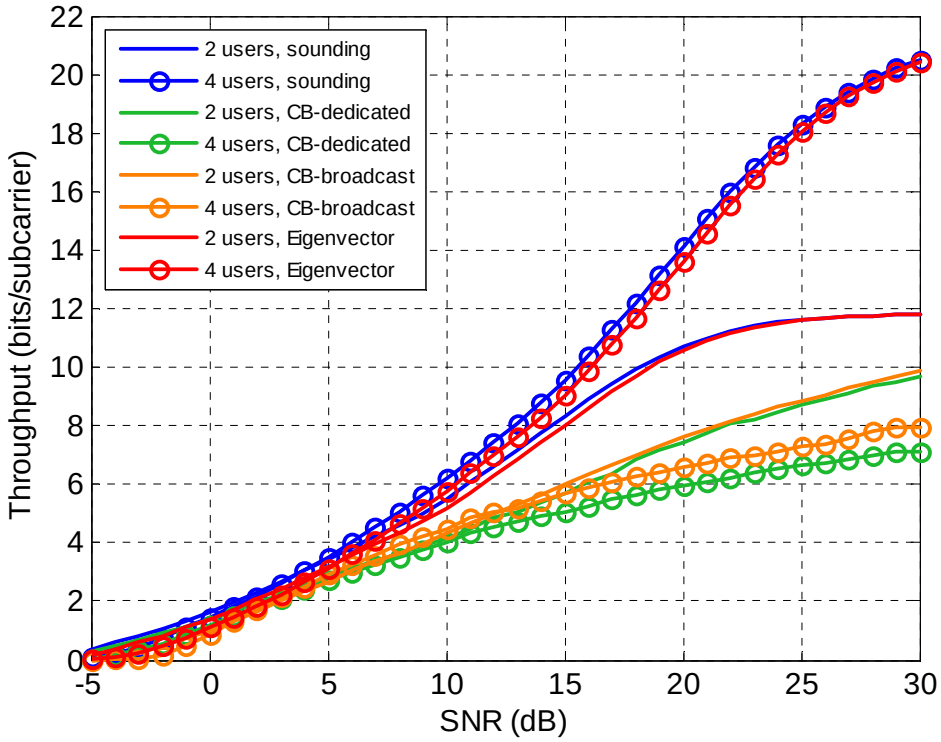


- Benefits seen by using dedicated pilots
  - Better performance at lower SNRs
  - Better performance for 8 Tx antennas

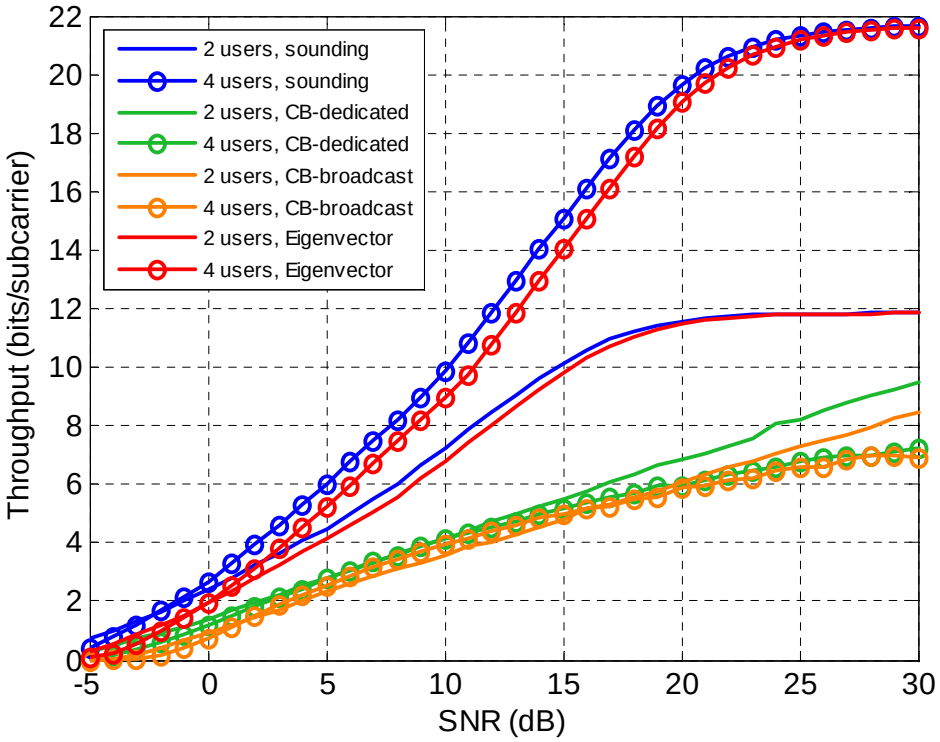
NOTE: pilot overhead is accounted for in the throughput results

Performance Comparisons for MU-MIMO

4 Tx, 2 Rx antennas



8 Tx, 2 Rx antennas



- For sounding (TDD) and Eigenvector feedback (FDD), MU-MIMO provides large throughput gains over SU-MIMO in this channel (at SNRs>5 dB)
- UL Sounding (TDD)/Eigenvector feedback (FDD) & dedicated pilots is better than codebook (CB) feedback for this scenario
- For Codebook Feedback: Dedicated pilots provide some advantage with 8 Tx
  - For 4Tx, broadcast pilots are marginally better, but require feed-forward of interferers' codebook entries

NOTE: pilot overhead is accounted for in the throughput results

Additional Topic: MIMO Midamble

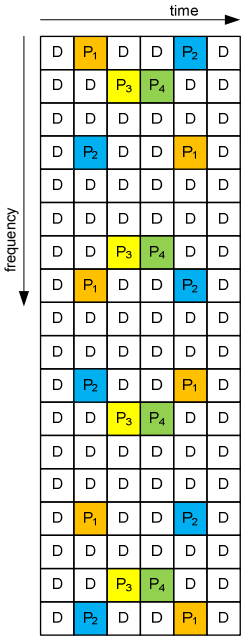
- Multi-antenna DL reference signal that enables the MS to determine the DL multi-antenna channel from the BS TX antennas
- Used for Precoding feedback, CQI & link adaptation, adaptation between MIMO modes, etc.
- Included as an option in 16e (up to 4TX).
- Need this capability in the 802.16m SDD for up to 8 TX

Outline of Recommendations for the SDD

- Localized resource tile and subchannel configurations contained in this contribution
  - Resource tile layout for dedicated pilots presented as a baseline
  - Subchannel allocation modes: diversity & narrowband allocation modes
- Must include support for resource tiles having dedicated pilots for data allocations
- Must include support for resource tiles having broadcast pilots for data allocations
- Frame structure impact:
  - SDD must include support for a “MIMO Midamble” in the frame structure to enable MIMO transmission
  - SDD must support feedback channels that support UL Channel Sounding / Direct/Analog feedback methods

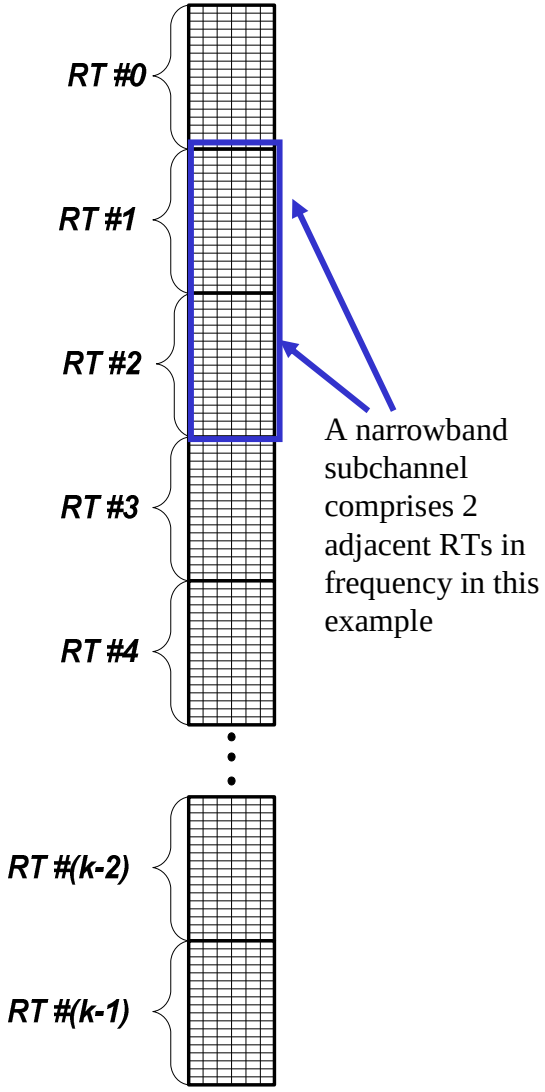
Specific Text Recommendations for SDD Section 11 – PHY Layer (1)

- Section 11.x: localized resource tile format for the downlink data channels
  - A localized resource tile (RT) format is supported with dedicated pilots for self-contained channel estimation. As shown in the figure, the basic RT is 18 subcarriers by 6 symbols and supports an arbitrary number of transmit antennas. The RT supports up to four spatial streams, where each spatial stream can be viewed as the third dimension (not shown) of the RT. In the figure, the symbols labeled "D" are data symbol locations where each spatial stream transmits a data symbol. The symbols labeled Pn are locations where stream n transmits a pilot symbol and all other streams transmit null symbols. Pilot locations for a stream that is not transmitted are replaced with data symbols D. In other words, if the number of transmitted streams is equal to m, then pilot locations Pm+1 through P4 are replaced with data symbols D. FEC rate matching is assumed throughout the RTs that make up a subchannel.

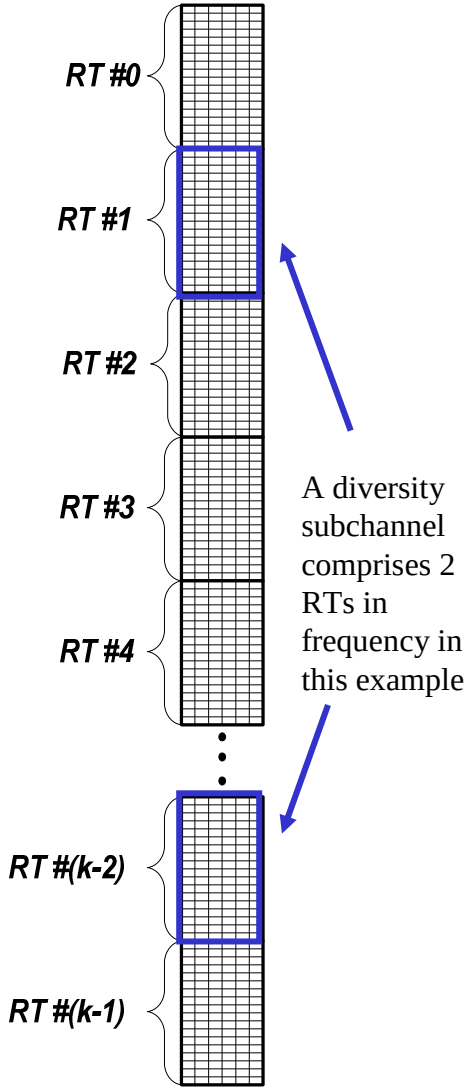


Specific Text Recommendations for SDD Section 11 – PHY Layer (2)

- Section 11.y: Grouping resource tiles into data subchannels
  - A subchannel comprises one or more resource tiles (RTs), where FEC is performed across the RTs that make up a subchannel. Two types of subchannels are defined. First, a narrowband subchannel comprises one to TBD RTs, where all RTs in the subchannel are adjacent in frequency. Second, a diversity subchannel comprises two to TBD RTs, where all RTs in the subchannel are separated in frequency in a manner that is TBD. FEC with rate matching is assumed across the RTs that make up a subchannel.



Narrowband Subchannel



Diversity Subchannel

Specific Text Recommendations for SDD Section 11 – PHY Layer (3)

- Section 11.d: Support for UL Feedback Channels
  - The frame structure provides feedback channels for supporting UL channel sounding and/or direct/analog feedback methods for enabling beamforming, SU-MIMO, and MU-MIMO transmission on the DL.
- Section 11.e: Support for MIMO midamble
  - The frame structure supports the scheduling of a MIMO Midamble for sounding the multi-antenna downlink channel to enable SU-MIMO and MU-MIMO.